Wuhan HP2016

Production of e^+e^- in U+U and Au+Au as Measured by STAR

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Office of Science U.S. DEPARTMENT OF ENERGY

RICE

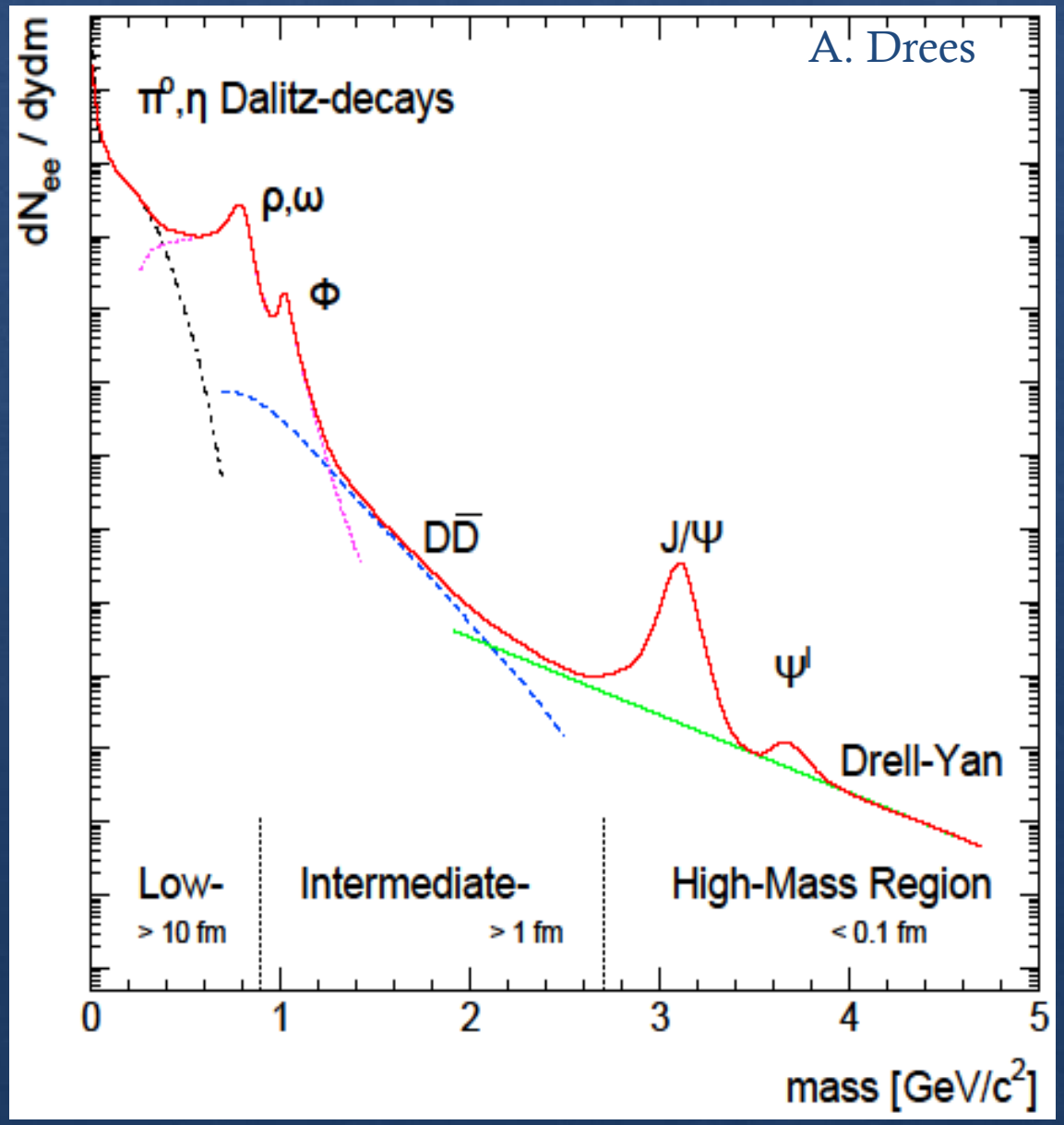
STAR

Outline

- Using e^+e^- to probe the medium
- Vector meson modification in the medium & lifetime measurement of the medium
- Measurements in U+U @ $\sqrt{s_{NN}}$ = 193 GeV
- Measurements in RHIC Beam Energy Scan
- Outlook
- Summary

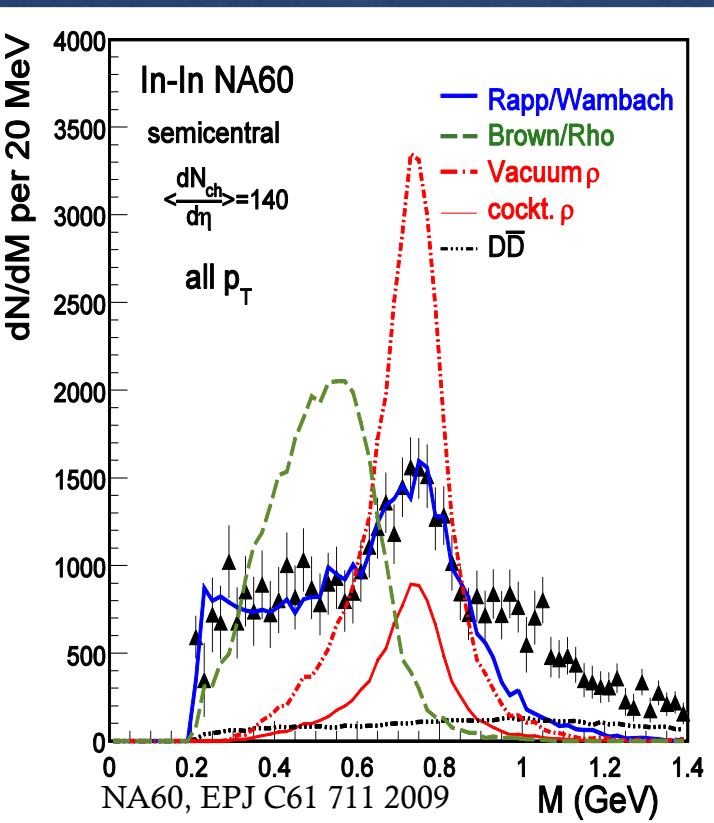
EM Probes

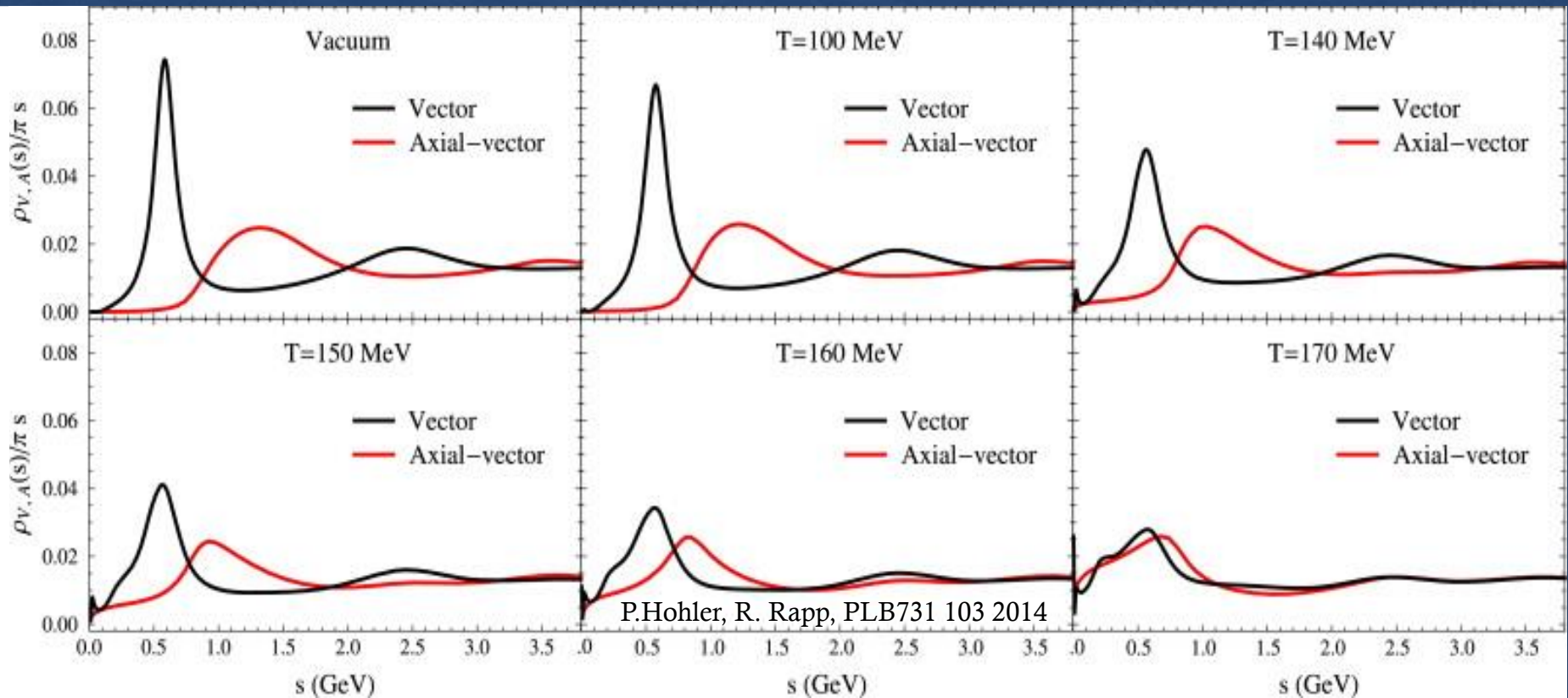
- **Excellent Probe**
  - Minimal final state interactions
  - Generated at all stages of the collision
- **Chronological Phases [Early to Latest]**
  - High Mass Region [HMR]
    - Drell-Yan
    - J/ψ + ϒ Suppression
  - Intermediate Mass Region [IMR]
    - Heavy flavor modification
    - QGP (thermal) radiation
  - Low Mass Region [LMR]
    - Vector meson modification
    - Possible link to chiral symmetry restoration



LMR: Spectral Functions

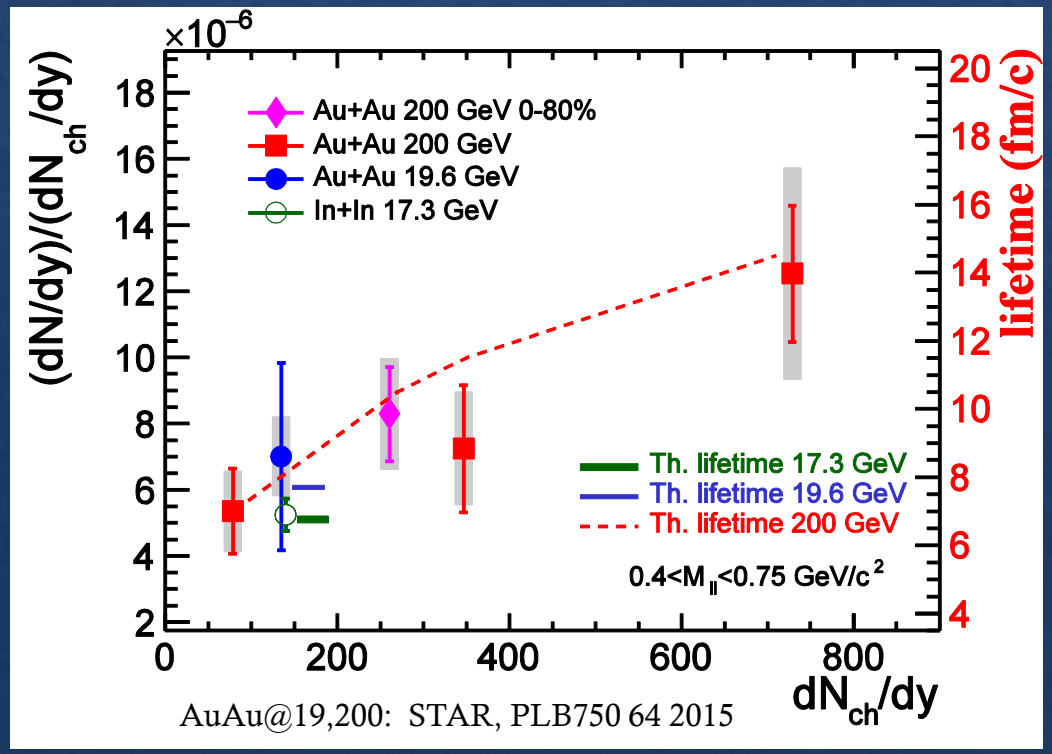
- Spectral functions modified in the medium
  - Successful description of data @ SPS & RHIC energies
- Possible link to chiral symmetry restoration
  - Spectral Functions + QCD Sum Rules + Weinberg Sum Rules + lQCD

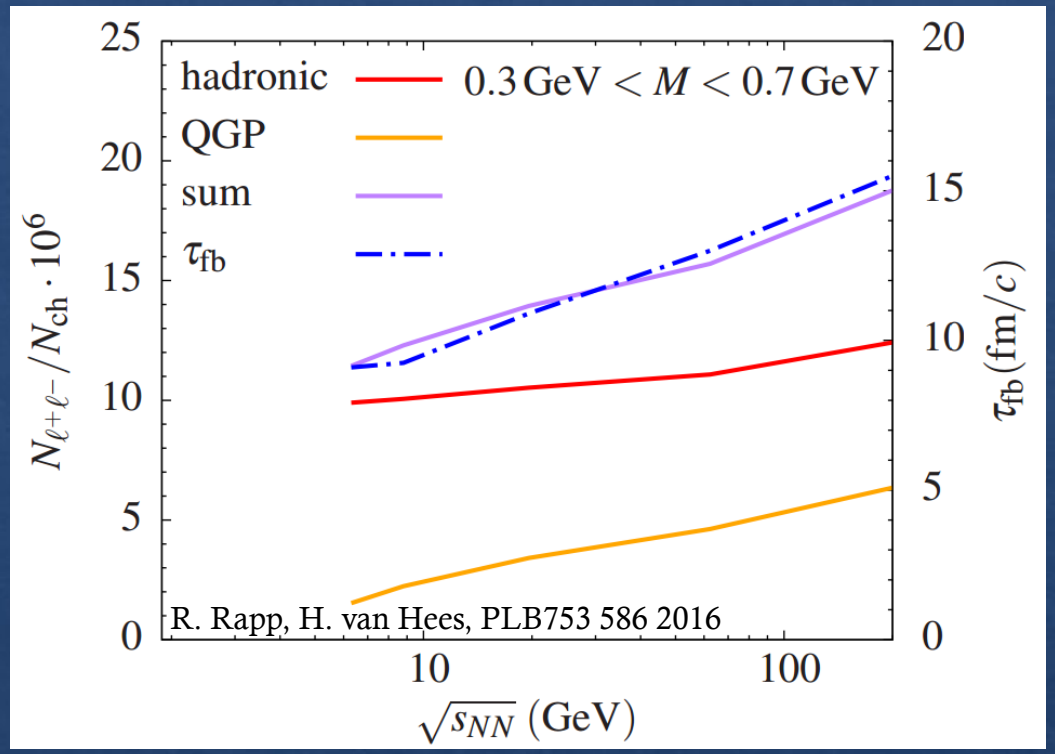




Lifetimes

- Lifetime of the fireball
  - Proportional to 'excess' in LMR

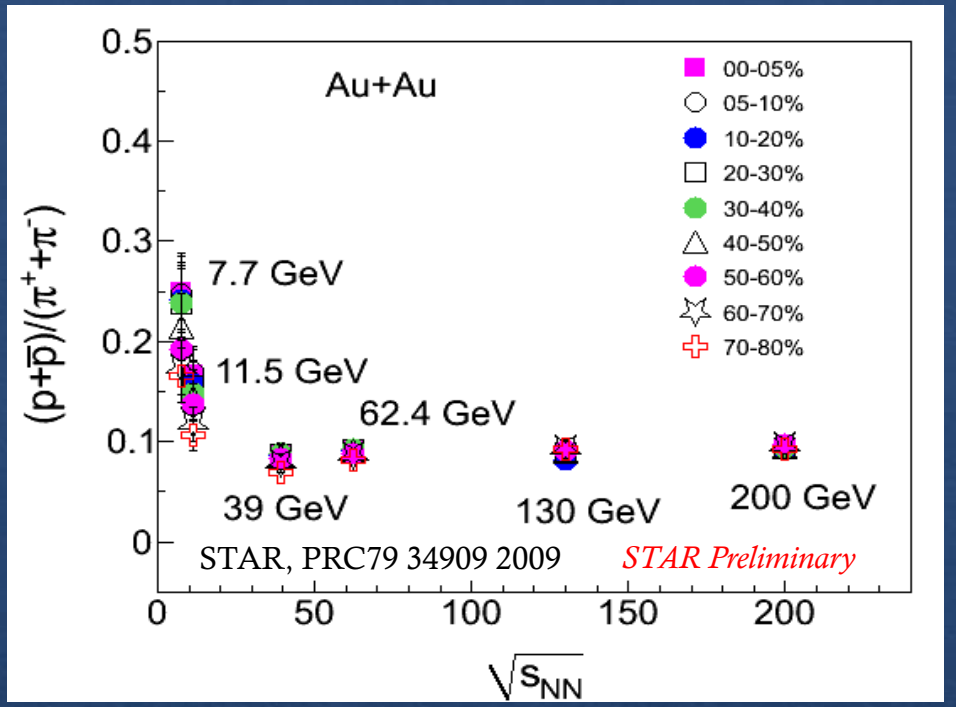


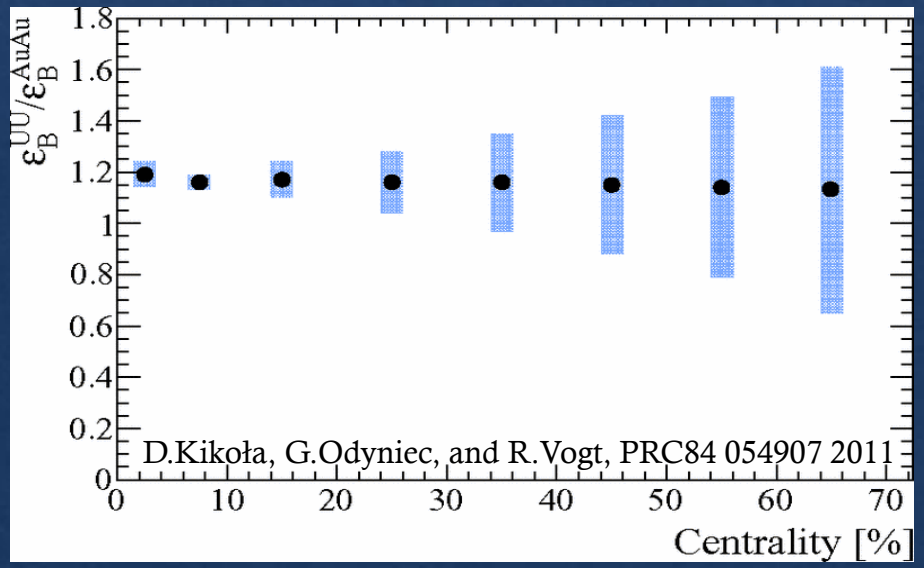


- 'Excess' Au+Au data
  - Greater at more central collisions
  - In agreement with model lifetime trends

Experimental Controls

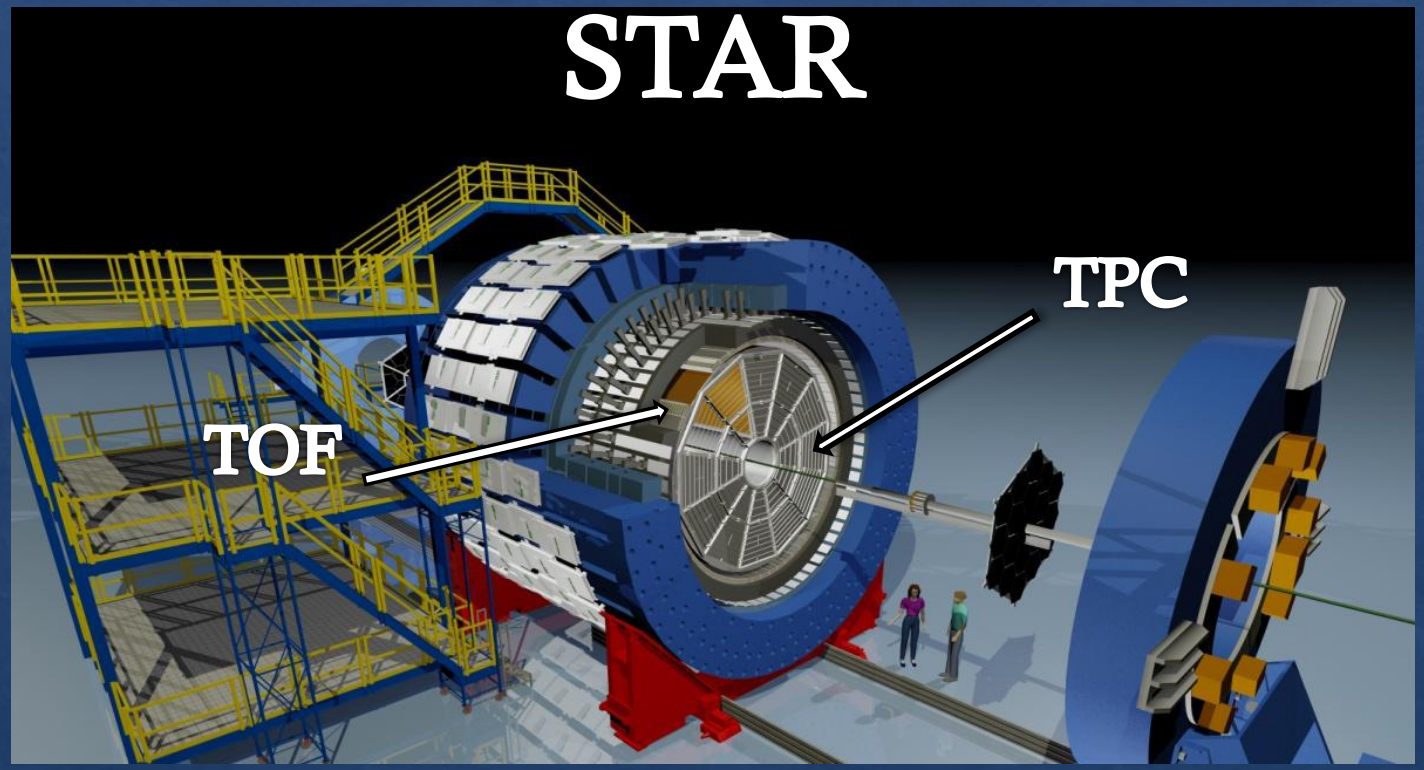
- From RHIC to SPS
  - Beam Energy Scan Program: 7.7 - 62.4 GeV
    - Ties RHIC to SPS
    - Sufficient data [Au+Au @ $\sqrt{s_{NN}}$ = 19.6, 27, 39, 62.4 GeV]
    - Change $\sqrt{s_{NN}}$, maintain colliding species & total baryon density
  - Systematically study the LMR excess yield
    - As a function of $\sqrt{s_{NN}}$
    - Versus fireball lifetime





- Higher energy densities + number of participants
  - Au+Au → U+U @ $\sqrt{s_{NN}}$ = 193 GeV
    - Energy density expected to be up to 20% higher than Au+Au @ $\sqrt{s_{NN}}$ = 200 GeV
  - Longer fireball lifetime?
  - Higher excess yield in the LMR?

Data

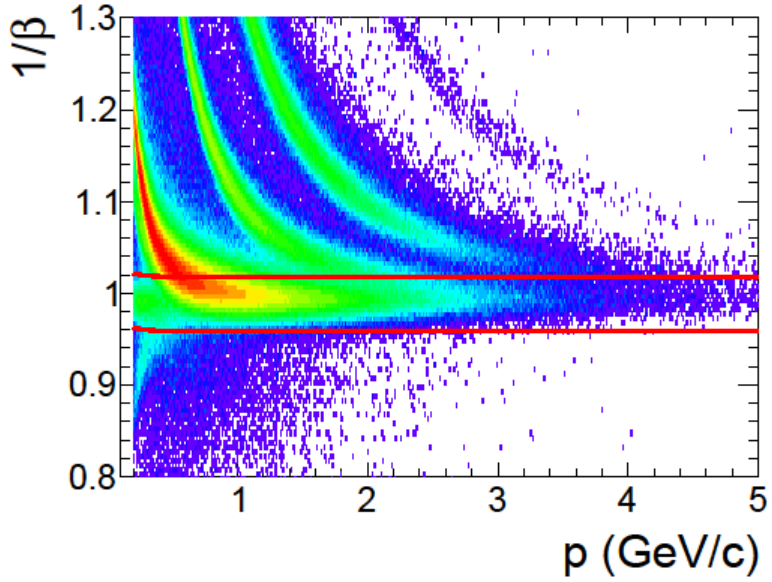


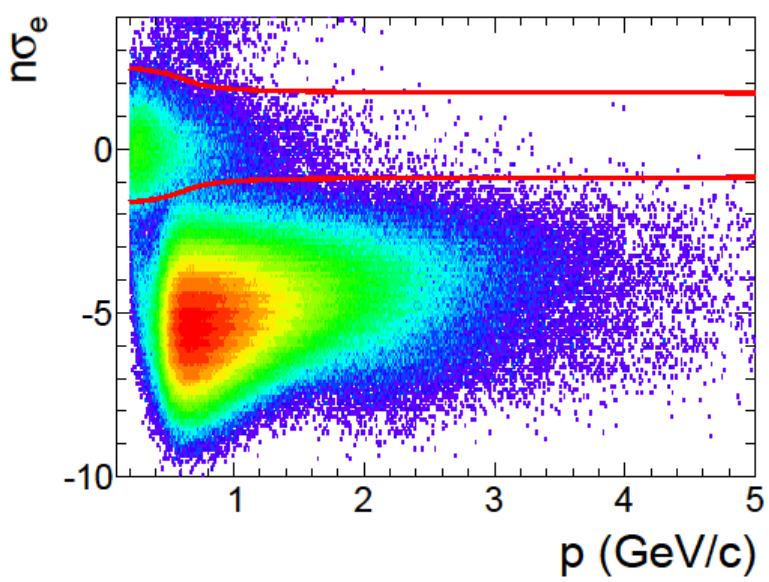
Species	$\sqrt{s_{NN}}$ [GeV]	Events (M)
Au+Au	200	730 (min. bias) + 220 (central)
Au+Au	62.4	67
Au+Au	39	130
Au+Au	19.6	36
Au+Au	27	70
U+U	193	270

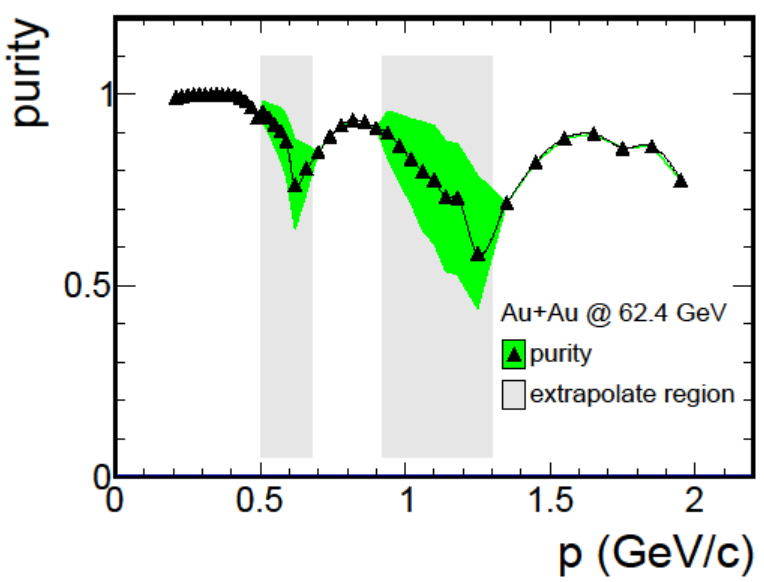
- Time Projection Chamber (TPC) and Time of Flight (TOF)
- Large acceptance (p_T^e>0.2 GeVc^{-1}, $|\eta^e|$<1, & $|Y_{ee}|$<1)

Electron Identification

Au+Au @ $\sqrt{s_{NN}} = 62$ GeV



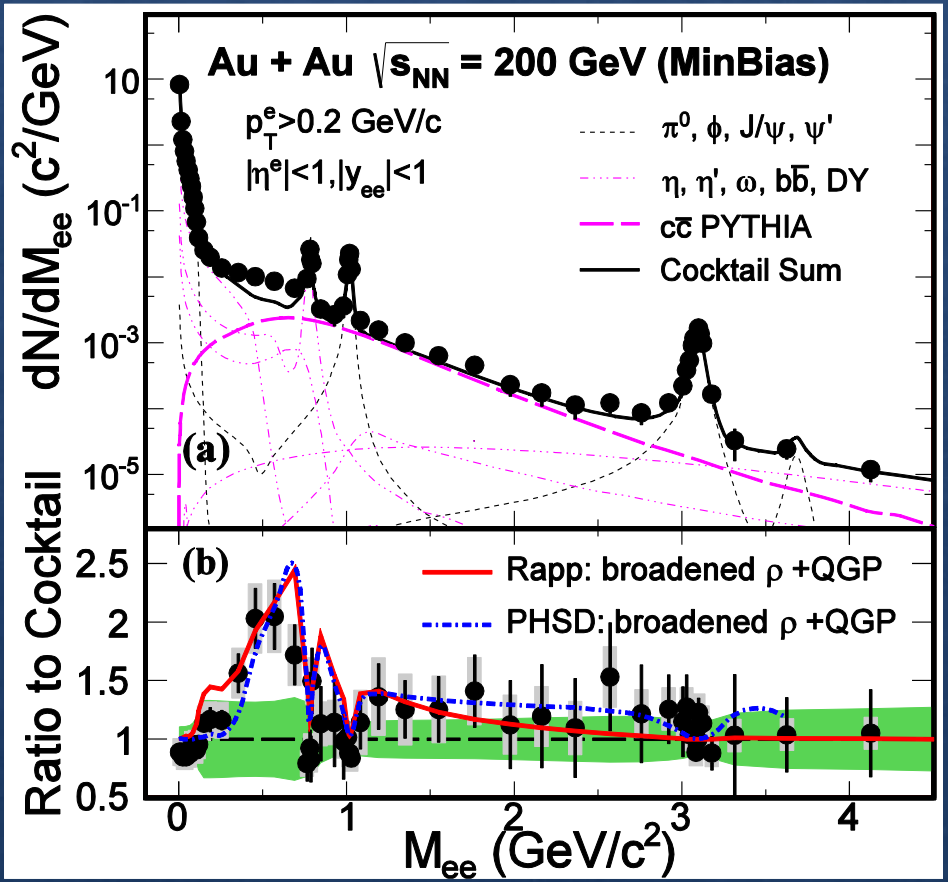




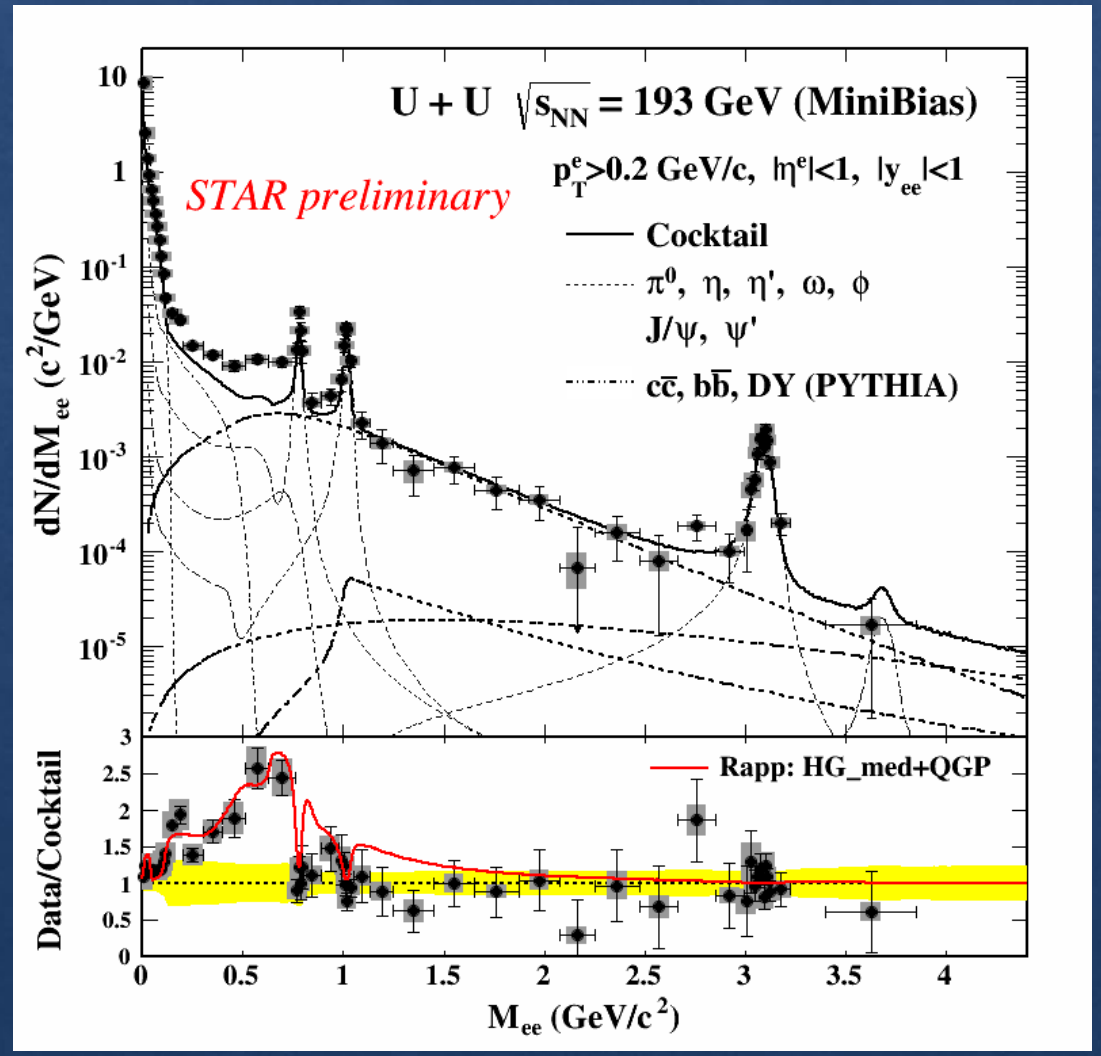
- Uses the TOF's precise timing
  - Remove slower hadrons
  - Extends and improves the TPC's PID reach
- High-purity detection of electrons
  - Integrated purity > 95%

Minimum-Bias Yields

- Different collision systems
- In good agreement with model(s) that incorporates ρ spectral function broadening

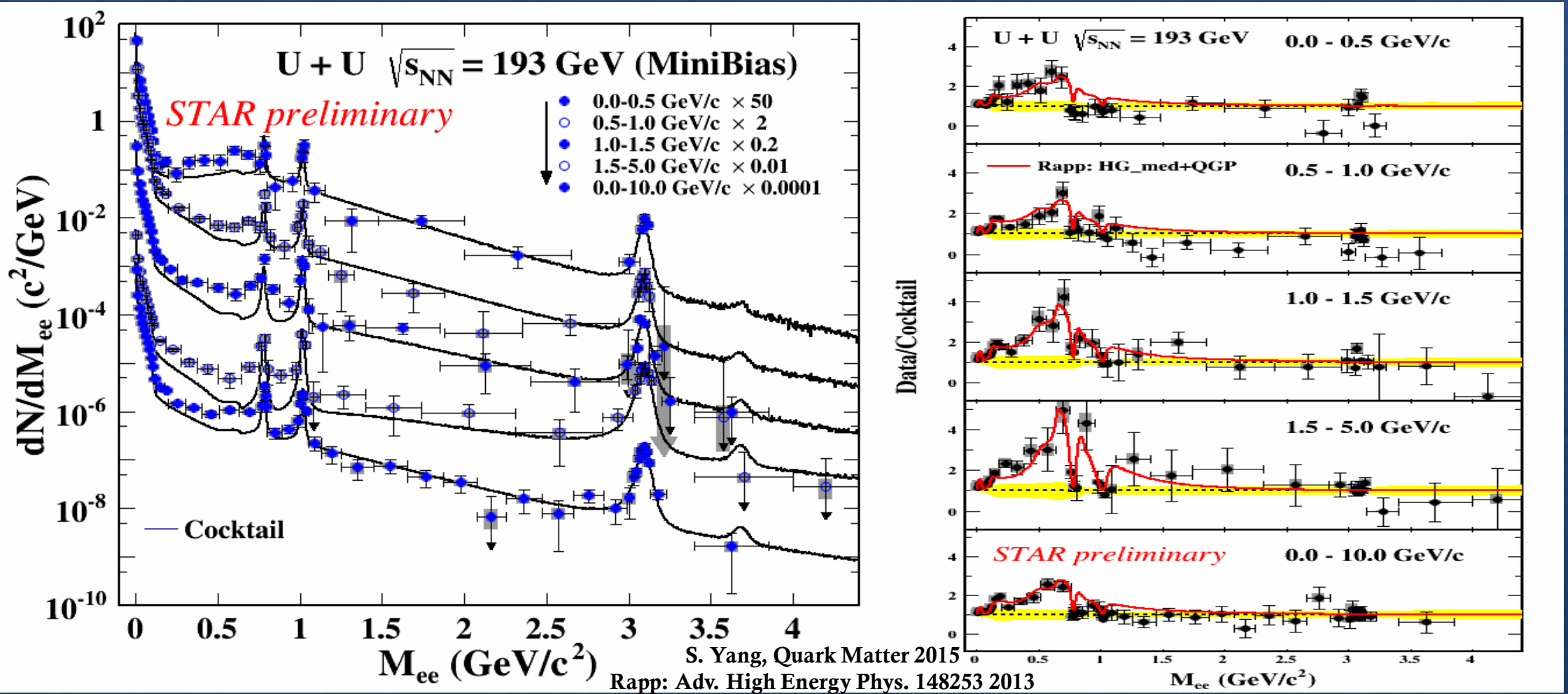


STAR, PRL113 22301 2014
Rapp: Adv. High Energy Phys. 148253 2013
PHSD: O. Linnyk et al., PRC 85 024910 2012



S. Yang, Quark Matter 2015
R. Rapp: Adv. High Energy Phys. 148253 2013

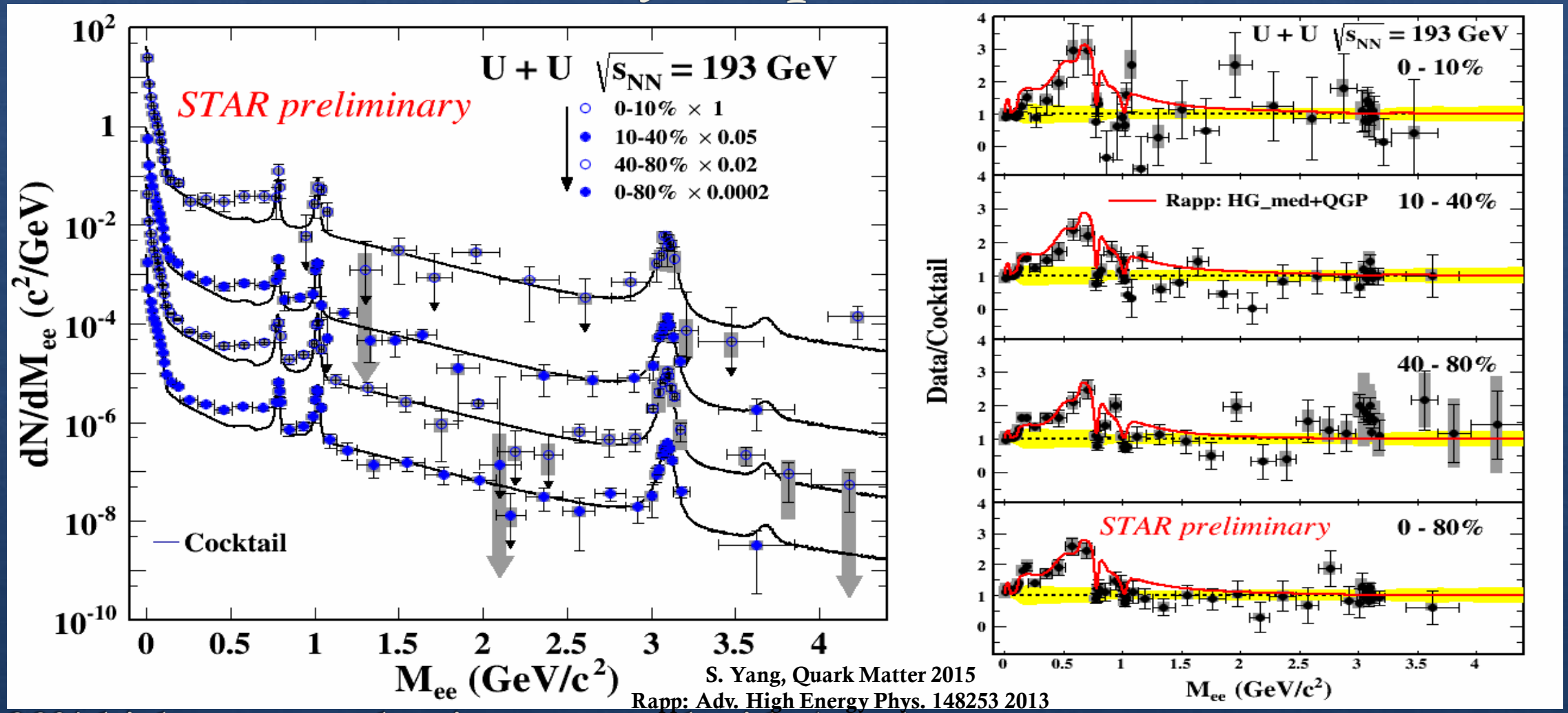
p_T Dependence: U+U



S. Yang, Quark Matter 2015
Rapp: Adv. High Energy Phys. 148253 2013

- 20% higher energy density compared with Au+Au
- Model, which incorporates the broadening of the ρ spectral function, is consistently in agreement in the LMR as a function of p_T

Centrality Dependence: U+U

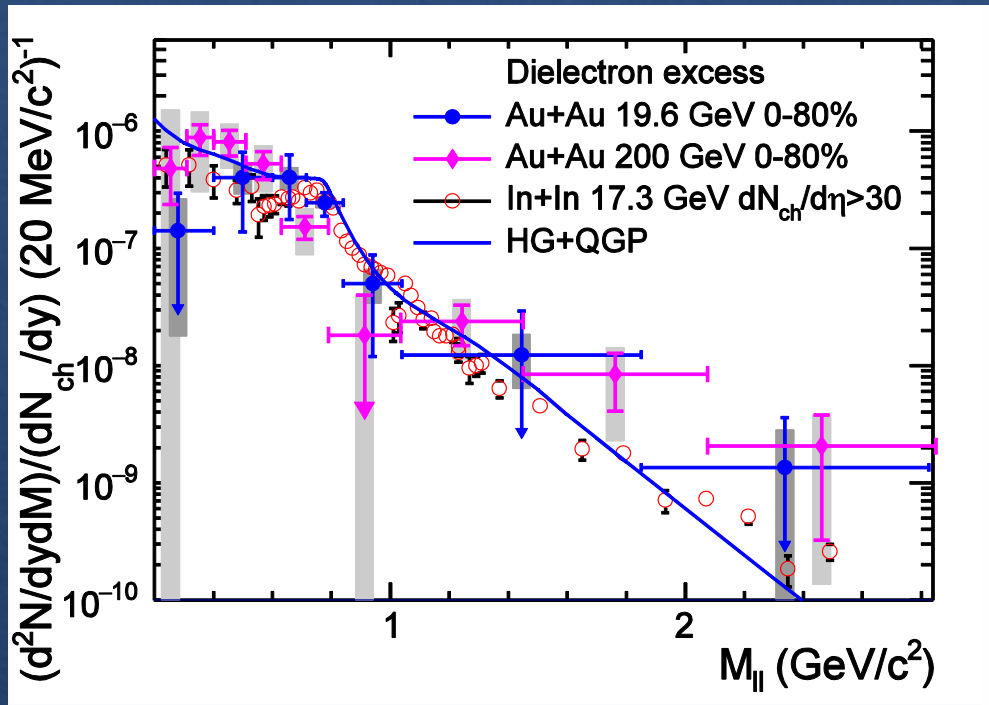


S. Yang, Quark Matter 2015

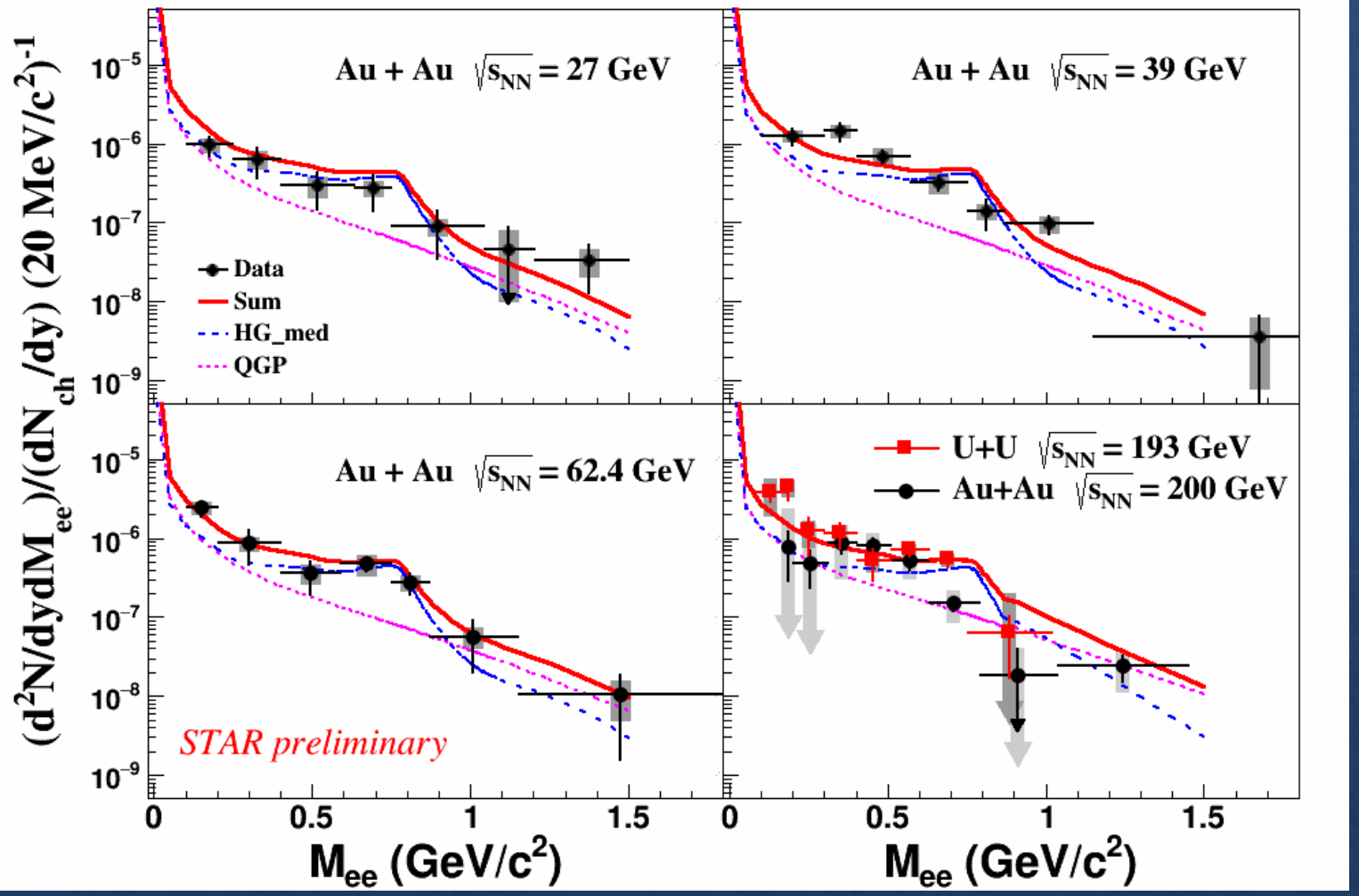
Rapp: Adv. High Energy Phys. 148253 2013

- 20% higher energy density compared with Au+Au
- Model, which incorporates the broadening of the ρ spectral function, is consistently in agreement in the LMR as a function of centrality

Normalized Excess Yield Acceptance-Corrected



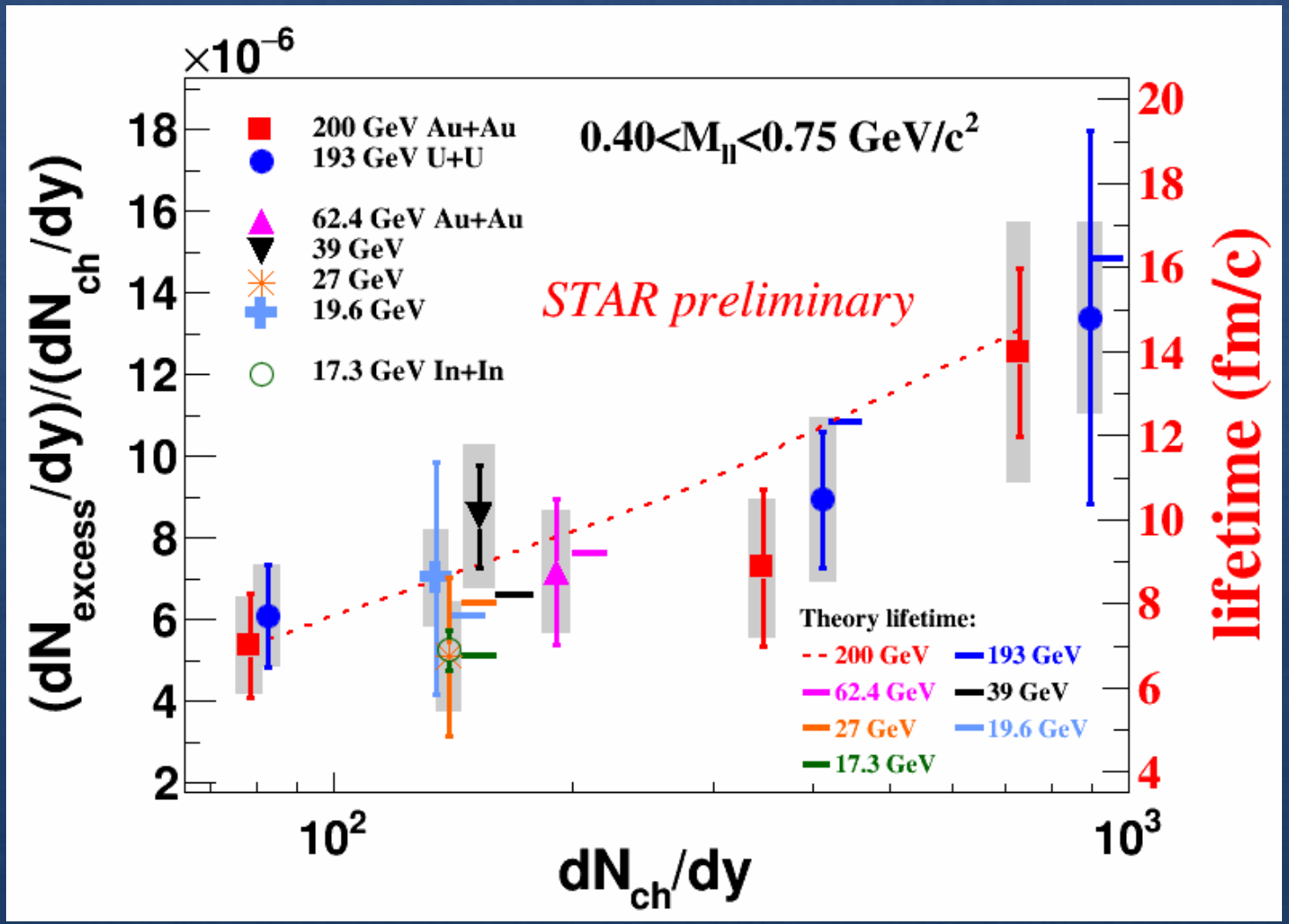
- Different initial conditions by changing energy density (species + $\sqrt{s_{NN}}$)
- In good agreement with a model that incorporates a broadened ρ spectral function



AuAu@19.6,200: STAR, PLB750 64 2015
AuAu@27,39,62&UU@193: S. Yang, QM15
InIn@17.3: NA60, EPJ C59 607 2009
Theory: R. Rapp PRC63 054907 2001 + priv. comm.

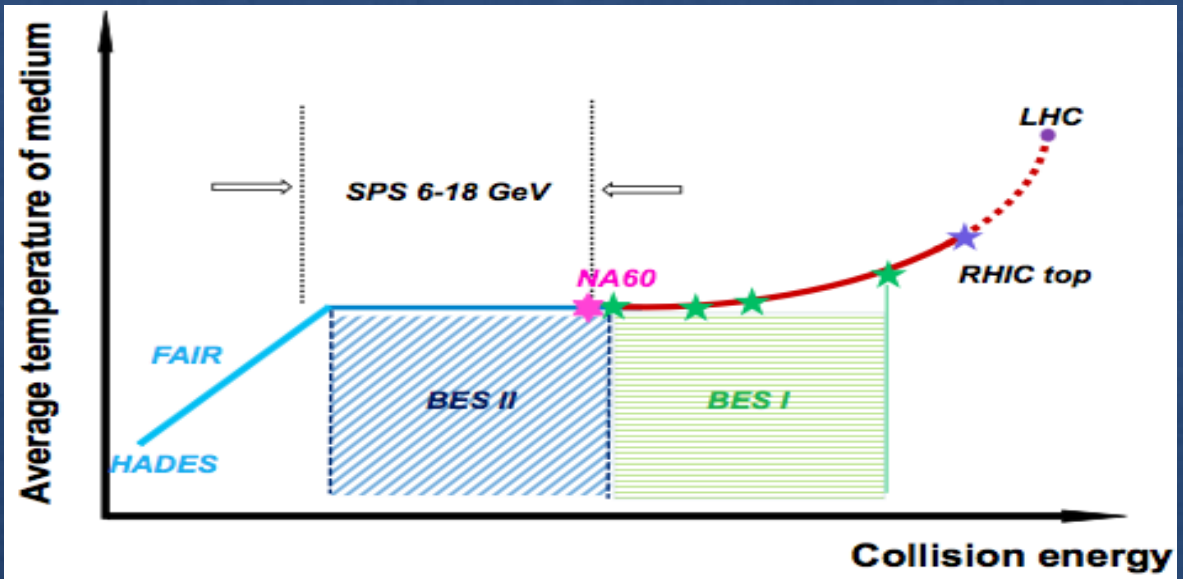
Lifetimes

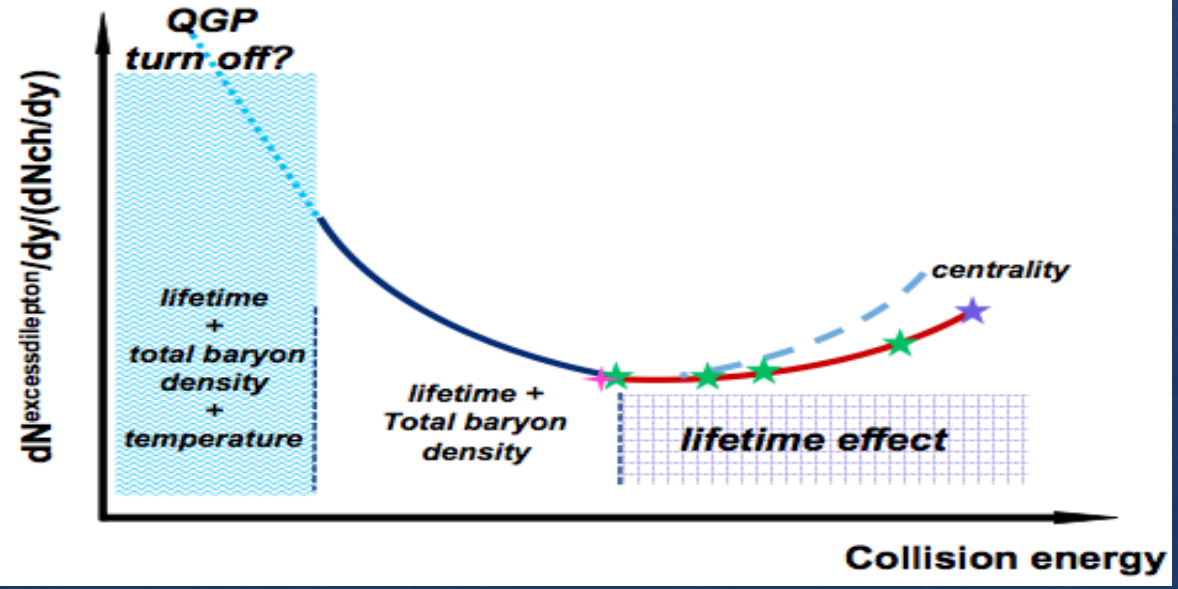
- **Model**: Normalized integrated excess yield in the LMR is proportional to the lifetime of the system for $\sqrt{s_{NN}}$ = 17.3 - 200 GeV
- Increase of yields
  - At higher energies with respect to lower energies
  - At central collisions compared to peripheral collisions
- Measurements are consistent with model calculations that report longer lifetimes for more central collisions



AuAu@19,200: STAR, PLB750 64 2015
AuAu@27,39,62 & UU@193: S. Yang, QM15
InIn@17.3: NA60, EPJ C59 607 2009
Lifetimes: R. Rapp, H. van Hees, PLB753 586 2016

Future e^+e^- Studies





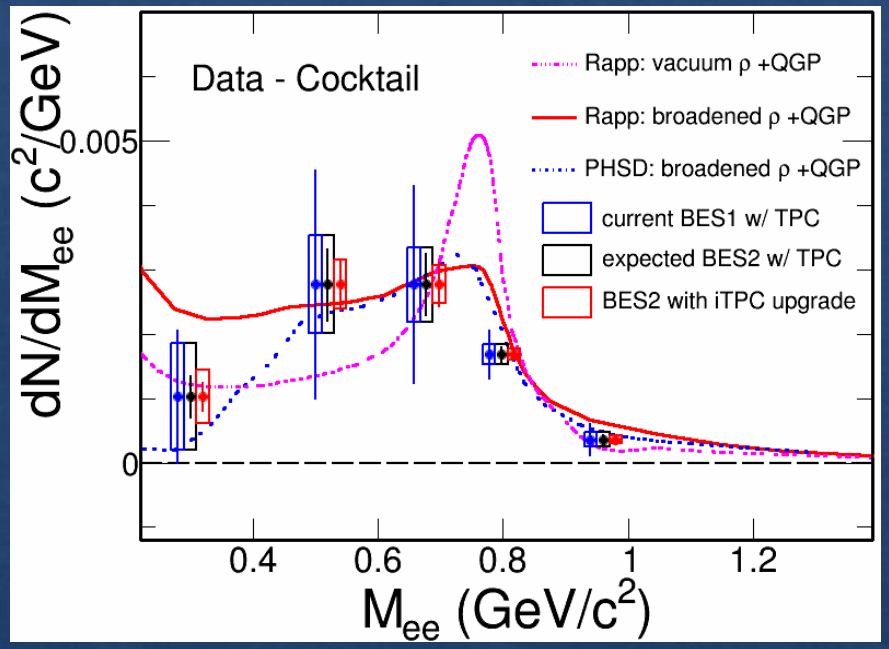
Ruan, Rapp – TPD'14

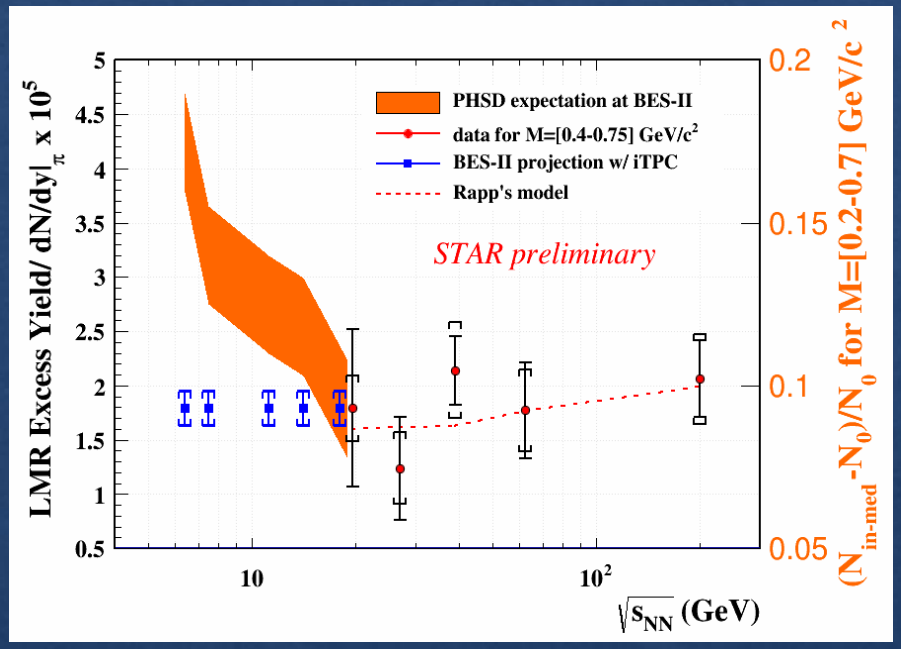
- BES-I investigated LMR emission & proportional to lifetime (w/ constant total baryon density)
- BES-II continue to probe LMR and investigate the lifetime and ρ spectral function dependence on total baryon density
  - If near critical point, possible increase in excess yields compared to the expected excess yield
- BES-II may allow for meaningful measurements of IMR
- Overlaps & spans $\sqrt{s_{NN}}$ that connects many experiments

Future e^+e^- Studies (cont.)

Au+Au @ $\sqrt{s_{NN}}$ [GeV]	7.7	9.1	11.5	14.5	19.6
Events (M)	100	160	230	300	400

Similar stat. uncert. as Au+Au @ $\sqrt{s_{NN}}$ = 200 GeV





- inner Time Projection Chamber
  - Reduction in statistical uncertainties
    - Quantity + acceptance increase
  - Reduction in systematic uncertainties
    - Cocktail + purity improvement

- end-cap Time Of Flight
  - Matches the reach of iTPC
  - Measure rapidity dependence → study total baryon density dependence

AuAu@19,200: PLB750 64 2015; AuAu@27,39,62: S.Yang, QM15;
R.Rapp PRC63 054907 2001 + R.Rapp, H.van Hees, PLB753 586 2016 + Priv. Comm.;
PHSD: O. Linnyk et al., PRC85 024910 2012

Summary

- STAR has an established LMR e^+e^- program measuring the invariant mass
  - Measurements as a function of $\sqrt{s_{NN}}$
  - Measurements as a function of p_T
  - Measurements as a function of centrality
  - Measurements as a function of collision species
- Our measurements agree with models, which include a broadened ρ spectral function
  - Measurements are consistent with a model that indicates a longer medium lifetime for collisions that are more central and have a higher $\sqrt{s_{NN}}$
- Outlook
  - BES-II offers an opportunity to build and extend the current program
  - Continue to study the relationship between excess yields and fireball lifetimes
  - Statistics may allow for IMR measurements

Thank you

Backup